Fallen wood decomposition of *Pinus koraiensis* and *Tilia amurensis*[1]

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Abstract Fallen wood decomposition rate of *Pinus koraiensis* and *Tilia amurensis* in broadleaved Korean pine forest was studied in this paper. The result showed that decomposition rate of fallen wood was different from that of little diameter wood and coarse woody debris for the same tree species. Fallen wood decomposition was generally rotten from outside to inside. And decomposition speed of fallen woods was different according to tree species and site, and it was also related to diameter of fallen woods. Decomposition depth of *Tilia amurensis* fallen wood for 17 years was 14 cm, but that of *Pinus koraiensis* in the same condition was less than 7 cm. *Tilia amurensis* was decomposed faster than *Pinus koraiensis*. For same tree species, if the diameter was small, the decomposition speed was quick.

Key words: Fallen wood decomposition, *Pinus koraiensis, Tilia amurensis*

Introduction

Snag and fallen wood was important components of forest ecosystem, nutrient pool for forest animals and microbes, also was important approach of energy flow and material flow in forest. So forest ecologists attached importance to study on snag and fallen wood increasingly and newly developed the "Ecology of Wood decomposition"[3,5,6].

In research work in Changbai Mountain Forest Ecosystem, the study [4,7,8,9,10] had been conducted in fallen wood since 80s, and the research range was very widespread. But these studies were mainly concerning sick and dead xylem decomposition of fallen wood, and mathematics models were developed for some tree species. The related research work was common for abroad. Undoubtedly, all these studies were important in finding out rules of fallen wood decomposition and rate of decomposition. But it had to be pointed out that most of these studies were limited in rules of weight varying per unit volume of sick and dead xylem and fallen wood, and rarely concerned to develop model on decomposition process and decomposition rate of whole fallen wood. Based on the above-mentioned decomposition process, rate for whole fallen wood of *Pinus koraiensis* and *Tilia amurensis* were studied using investigation data of fallen wood decomposition. As a supplement of the related studies, the decomposition process and rate of fallen wood were comparatively studied by developing model on fallen wood decomposition in research of Changbai Mountain Forest Ecosystem.

Development mathematics model on decomposition of whole fallen wood

Density varying during fallen wood decomposition

Fallen wood decomposition was a complex process of biological physical chemistry. Although there were a lot of studies on fallen wood decomposition, mechanism of fallen wood decomposition was not clarified up to now. So, there was no unified knowledge on rule of decomposition in terms of theory. The mathematics models mainly were experimental models. In research work at Changbai Mountain Forest Ecosystem, the mathematics models of fallen wood decomposition mainly were individual exponent attenuation models such as equations (1) and (2).

$$y = Ae^{-Bx} \tag{1}$$

$$p_x = e^{-Bx} \tag{2}$$

here: y means density of fallen wood and x means time for small fallen wood; P was equivalent to e^{-B} and means decomposition rate; p_x means decomposition rate in x years running.

Variation of wood decomposition depth

Except of heart rotting of trees, fallen wood decomposition was generally rotten from exterior to interior. Although the bark, which was full of nutrient, was easy to decompose, wood was rotten slowly. The heartwood had a lot of fiber and xylem, which were difficult to decompose. The decomposition process was different for different trees and their site conditions. And studies about this way were few because the data were difficult to be acquired. So, research for fallen woods of different ages and decomposition of different depth could find out the relationship between decomposition depth and decomposition ages.

Relationship between decomposition depth and density The wood density (y) was in linear relation with wood decomposition depth (x) and the relation was obvious. So

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equation (3) was used to describe the relationship between decomposition depth and density.

$$y = A + Bx \tag{3}$$

Relationship between decomposition depth and age
According to different decomposition depth (y) with different age (x), the relation between them was found obvious. Equation (4) was used to describe the relationship of them.

$$y = Ax^B \tag{4}$$

Mathematics models of fallen wood decomposition
According to equation (2) and (4), mathematics models of fallen wood decomposition were developed as follows.

When the decomposition time was one year, the equation was:

$$y_1 = Q\pi\left[R^2 - (R - Ax_1^B)^2\right]e^{-Bx1} \times L$$

When the decomposition time was two years, the equation was:

$$y_2 = Q\pi\left\{\begin{matrix}\left[R^2 - \left(R - Ax_1^B\right)^2\right]e^{-Bx_2} + \\ \left[\left(R^2 - Ax_1^B\right)^2 - (R - Ax_2^B)\right]e^{-Bx_1}\end{matrix}\right\} \times L$$

When the decomposition time was n (a positive integer) years, the equation was:

$$y_n = Q\pi\sum_{x=1}^{n}\left[(R - A(x-1)^B)^2 - (R - Ax^B)^2\right] \times e^{-B(n+1-x)} \times L$$

In these equations, y means the density of fallen wood decomposition; x means age or age sequence of fallen wood decomposition and x=1, 2, $\cdots$, n; Q means density of wood; L means length of wood; R means diameter (unit: cm) of the middle segment of the fallen wood; A and B were experimental parameters.

If $L = 1$, the above equations were transformed to equation (5).

$$y_n = \begin{cases} \sum\limits_{x=1}^{n} y_x = Q\pi\sum\limits_{x=1}^{n} e^{-B(n+1-x)}\left[(R - A(x-1)^B)^2 - (R - Ax^B)^2\right], & x \le \left(\frac{R}{A}\right)^{\frac{1}{B}}; \\ y = 0, & x > \left(\frac{R}{A}\right)^{\frac{1}{B}}. \end{cases} \tag{5}$$

Relationship between decomposition age and decomposition depth
To understand forest self–thinning, to find out the annual varying rule of forest litter–loss ratio and to determine decomposition in different depth and utilization value of fallen woods, it was necessary to know time of snag and fallen wood. Then, wood sample was collected in sapwood of fallen wood. Density was measured and decomposition age (x) was determined by equation (6) according to equation (2).

$$x = \frac{\ln P_x}{B} \tag{6}$$

Equally, if decomposition age (x) was known, decomposition ratio and decomposition parameter (B) could be calculated by equation (2). Then decomposition in a certain depth or layer could be determined easily. For example, according to equation (4), time (x) of decomposition for a certain depth or layer (m) could be calculated.

If $m = Ax^B$, then $x = \left(\frac{M}{A}\right)^{\frac{1}{B}}$. According to equation (5), decomposition density (y) of a certain depth (m) could also be calculated by equation (7).

$$y = Q\pi\sum_{x=1}^{n}\left[(R - A(x-1)^B)^2 - (R - m)^2\right]e^{-B(n+1-x)} \tag{7}$$

Where, $m \le R$ and $x \le \left(\frac{R}{A}\right)^{\frac{1}{B}} + 1$.

Decomposition models of fallen wood of *Pinus Koraiensis* and *Tilia amurensis*

Decomposition models of fallen wood of *Pinus koraiensis*
According to Table 1, decomposition depth with different decomposition ages was calculated by equation (3), and the results were in Table 2. The mean relation coefficient was 0.95756 and the standard deviation was $\pm$ 0.04.

Table 1. Mean density with different decomposition depth of *Pinus koraiensis* fallen wood

Layer depth /cm	Age /a								
	0	1	3	4	7	8	10.5	16	45
0.5	0.3839	0.3789	0.3673	0.3505	0.3163	0.2908	0.2705	0.1830	0.1261
2.0	0.3893	0.3845	0.3751	0.3549	0.3374	0.3390	0.3170	0.2656	0.2120
3.5	0.3993	0.3947	0.3828	0.3732	0.3612	0.3439	0.3309	0.3149	0.240

Table 2. Density depths with different decomposition ages of *Pinus koraiensis* fallen wood

	Decomposition age /a							
	1	3	4	7	8	10.5	16	45
Decomposition depth /cm	1.6	3.7	5.2	6.0	6.2	6.6	6.6	9.3

According to data in Table 2, the relationship between decomposition depth (y) and decomposition age (x) was

$$y = 2.2x^{0.4351} \qquad (R=0.92908).$$

According to equation (5), decomposition model of fallen wood of *Pinus koraiensis* was equation (8).

$$y_n = \begin{cases} \sum_{x=1}^{n} y_x = Q\pi\sum_{x=1}^{n} e^{-0.0183\ (n+1-x)}\left[(R-2.2\ (x-1)^{0.4351})^2 - (R-2.2\ x^{0.4351})^2\right] & x \le (\frac{R}{2.2})^{\frac{1}{0.4351}}; \\ y = 0, & x > (\frac{R}{2.2})^{\frac{1}{0.4351}} \end{cases} \tag{8}$$

The relation coefficient of equation (8) was 0.88965. y means decomposition of *Pinus koraiensis* fallen wood when length (L) was 1. x means age or age sequence of fallen wood decomposition, and x=1, 2, ⋯, n. Q means density of *Pinus koraiensis* and equals to 0.3839.

Decomposition models of fallen wood of *Tilia amurensis*

According to data (Table 3), density of *Tilia amurensis* fallen wood was related to different layer, decomposition depth with different decomposition ages was calculated by equation (3) and the results were in Table 4. The mean relation coefficient was 0.97463 ± 0.03.

Table 3. Mean density with different decomposition depth of *Tilia amurensis* fallen wood

Layer depth /cm	Age /a				
	0	5	7	16	22
0.5	0.4262	0.3743	0.3344	0.2669	0.2067
2.0	0.4595	0.3938	0.3799	0.2859	0.2479
3.5	0.4708	0.4199	0.3878	0.3285	0.2901

Table 4. Density depths with different decomposition ages of *Tilia amurensis* fallen wood

	Decomposition age /a			
	5	7	16	22
Decomposition depth /cm	7.2	8.0	16.2	14.1

According to data in Table 2, the relationship between decomposition depth (y) and decomposition age (x) was

$$y = 2.9x^{0.549} \quad (R=0.94175) \tag{9}$$

The relation coefficient of equation (10) was 0.91786. y means decomposition density of *Tilia amurensis* fallen wood when length (L) was 1. x means age or age sequence of fallen wood decomposition, and x=1, 2, ⋯, n. Q means density of *Tilia amurensis* and equals to 0.4595.

According to equation (5) and (9), decomposition model of fallen wood of *Tilia amurensis* was equation (10).

$$y_n = \begin{cases} \sum_{x=}^{n} y_x = Q\pi\sum_{x=1}^{n} e^{-0.0275\ (n+1-x)}\left[(R-2.9\ (x-1)^{0.549})^2 - (R-2.9x^{0.549})^2\right] & x \le (\frac{R}{2.9})^{\frac{1}{0.549}}; \\ y = 0, & x > (\frac{R}{2.9})^{\frac{1}{0.549}} \end{cases} \tag{10}$$

Comparison of decomposition rate of *Pinus Koraiensis* and *Tilia amurensis* fallen wood

As above-mentioned, decomposition speed of *Pinus koraiensis* fallen wood with the same volume was slower than that of *Tilia amurensis*, and it was about 66% of the decomposition speed of *Tilia amurensis*. The decomposition depth of *Pinus koraiensis* was also shallower than that

of *Tilia amurensis*. For example, the decomposition depth of *Tilia amurensis* fallen wood which had been decomposed for 17 years was 14 cm, and that of *Pinus koraiensis* was 7.5 cm. It was obvious that decomposition speed of *Tilia amurensis* fallen wood was faster than that of *Pinus koraiensis*. The annual increase speed of fallen wood decomposition of *Tilia amurensis* was also bigger than that of *Pinus koraiensis*. The reason was that *Tilia amurensis* wood was soft and with more nutrient, and it was decomposed easily by insects and microbes.

Generally, if the diameter of fallen wood was small, the decomposition speed was high. Certainly, fuller was decomposition, the longer was time of decomposition and the bigger was the mean decomposition rate.

Conclusions

The rules of fallen wood decomposition were found out by using the developed decomposition models of *Pinus koraiensis* and *Tilia amurensis* fallen woods

Decomposition speed of fallen woods was different according to tree species and site, and it was also related to diameter of fallen woods.

For one tree species, if the diameter was small, the decomposition speed was quick. Decomposition rates with different diameter could be calculated by equation (5).

References

1. Jenny H., S. P. Gessel, and T. Bingham. 1949. Comparative study on decomposition rates of organic matter in temperate and tropical region. Soil Sci. 68:419~432.
2. Olson, J. S. 1963. Energy, storage and the balance of produces and decomposers in ecological system. Ecology. 44:322~331.
3. Swift, M. J. 1997. The Ecology of Wood Decomposition. Sci. Pro. Pxf. 64:175~199.
4. Heal, Cheng Borong, *et al.* 1983. Stamp decomposition of Korean pine and Changbai larch in Changbai Mountain. In: Forest Ecosystem Research Vol. 3. Bejing: Chinese Forestry Press, 225~234 (in Chinese).
5. Chen Hua, et al. 1991. The history, present situation and tendency of study on coarse woody debris. Journal of Ecology. 10(1): 45~50 (in Chinese).
6. Hao Zhanqing, *et al.* 1989. An overview of the roles of coarse woody debris in forest ecosystem. Advances in Ecology. 6: 179~183 (in Chinese).
7. Hao Zhanqing. 1988. The roles of fallen trees on regeneration of ermanii-spruce-fir forests in northern slope of Changbai mountain. Master Dissertation (in Chinese).
8. Dai Limin, *et al.* 1994. Models for decomposition and storage of fallen trees in the mixed broadleaved and Korean pine forest and the nutrition dynamics in the decomposition. Acta Ecologica Sinica. 14 (Supp.): 1~8 (in Chinese).
9. Dai Limin, *et al.* 1995. Composition and storage of fallen trees and snags in different elevation spruce–fir forest at Changbai Mountain. Acta Ecologica Sinica. 15 (Supp. B): 93~98 (in Chinese).
10. Chen Hua, *et al.* 1991. Initial study on trees death in broadleaved Korean pine mixed forest, Changbai Mountain. Chin. J. Appl. Ecol. 2 (1): 89~91 (in Chinese).
11. Chen Hua, *et al.* 1992. Dynamic study of coarse woody debris in temperate forest ecosystem. Chin. J. Appl. Ecol. 3 (2): 99~104 (in Chinese).

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